

# Low-frequency noise in AlSb/InAs HEMTs

W. Kruppa, J.B. Boos, B.R. Bennett and M.J. Yang

Measurements of the low-frequency noise in several types of AlSb/InAs HEMTs are reported. The slope of the noise level with frequency is close to ideal  $1/f$  for some types, while others have significant generation-recombination components. The Hooe parameter,  $\alpha_H$ , for all the devices is in the range between  $10^{-3}$  and  $10^{-2}$  based on floating-gate measurements at low drain voltage.

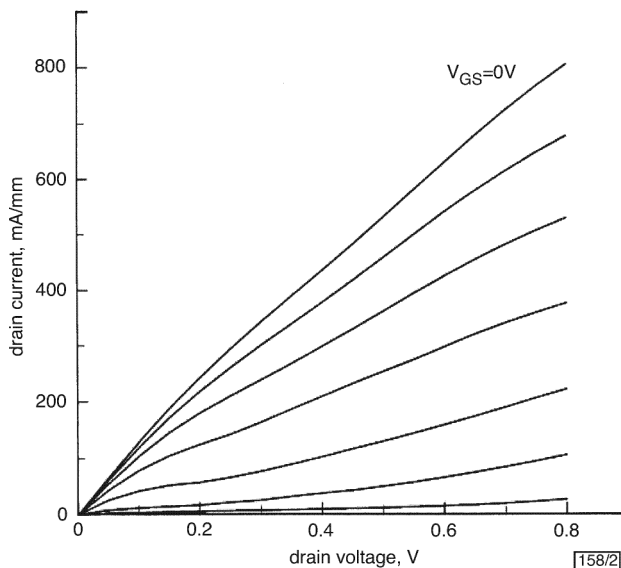
**Introduction:** The potential of AlSb/InAs high electron mobility transistors (HEMTs) for microwave- and millimetre-wave applications has been addressed during recent years. The excellent transport properties of InAs, such as high mobility and velocity, and the large conduction band offset between AlSb and InAs, leading to better charge confinement and high sheet charge density, have been discussed. Intrinsic  $f_T$  values of 250GHz have been obtained for devices with a  $0.1\mu\text{m}$  gate length at a drain voltage of only 0.6V [1]. This result implies potential application in low-bias-voltage circuits.

In this Letter, measurements of the low-frequency noise characteristics of several types of AlSb/InAs HEMTs are reported. The low-frequency noise is of interest for two reasons. First, this noise is a very sensitive indicator of material quality, particularly at the interfaces, and therefore can be used to fine-tune material composition and growth parameters. Secondly, since this noise is upconverted in various circuit applications, it constitutes a predictor of the phase noise in oscillators and phase jitter in digital circuits.

InAs 20Å
In <sub>0.5</sub> Al <sub>0.5</sub> As 50Å
AlSb 125Å
InAs 150Å
AlSb 2.4Å
Si GaAs substrate

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**Fig. 1** Material cross-section of HEMT type (i)



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**Fig. 2** Normalised drain characteristics of HEMT type (i)

Gate voltage steps are  $-0.1\text{V}$  starting from top

**Device structure and fabrication:** The HEMTs are fabricated using AlSb/InAs heterostructures grown by MBE on semi-insulating GaAs (001) substrates with a thick AlSb buffer layer to accommodate the 7% lattice mismatch. Four types of devices are considered in this Letter. Device type (i), which serves as the reference device, has the material cross-section shown in Fig. 1. It has no intentional doping. The channel

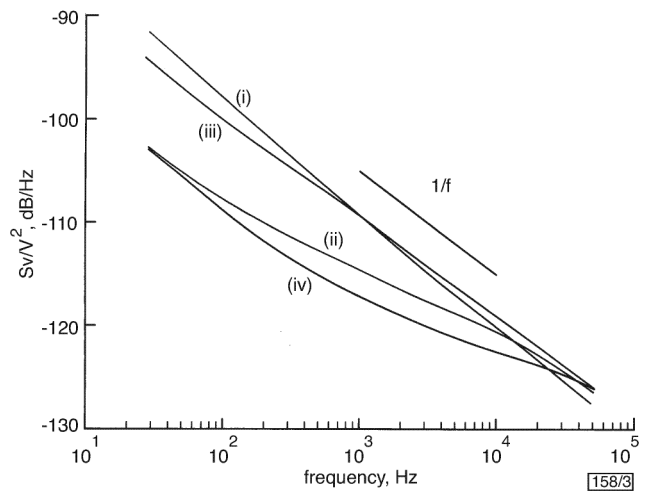
of this device has a mobility of  $29,000\text{cm}^2/\text{Vs}$  and a carrier concentration of  $9 \times 10^{11}\text{cm}^{-2}$  at 300K [2]. The normalised drain characteristics obtained for this HEMT with a  $0.1\mu\text{m}$  gate length are shown in Fig. 2. Device (ii) is a more advanced design with an InAs(Si) doping layer in the AlSb upper barrier as well as additional subchannel and  $p^+$  layers in the AlSb barrier below the channel which mitigate the effects of impact ionisation [1]. Device (iii) is the same as device (ii) except that the ohmic contacts are not alloyed. Device (iv) is the same as device (i) except for the addition of the InAs(Si) doping layer and the absence of the InAlAs barrier layer [3]. All the HEMTs considered in this Letter have a submicrometre gate length with a drain-source spacing of  $4\mu\text{m}$  and a width of  $30\mu\text{m}$ . The ohmic contacts are formed using Pd/Pt/Au metallisation, yielding typical resistances in the range of 0.1 to  $0.2\Omega\text{mm}$ .

**Noise measurements:** The noise measurements were made between 1Hz and 100kHz using a probing system, low-noise amplifier, and spectrum analyser. A constant current was applied to the device drain. The measurements were performed at low drain voltages in order to avoid high-field complications such as impact ionisation. Moreover, in the results reported in this Letter, the gate was kept floating to avoid additional complications related to gate leakage current. It should be noted, however, that the noise level was generally the same with the gate floating or tied to the source. Several samples were selected for measurement from each device type to ensure that the results are representative of the four HEMT structures being compared.

The normalised noise level is commonly characterised by the empirical relationship

$$\frac{S_V}{V^2} = \frac{\alpha_H}{f^\gamma N} \quad (1)$$

where  $S_V$  is the voltage noise power spectral density at frequency  $f$ ,  $V$  is the applied voltage,  $N$  is the total number of carriers in the sample, and  $\alpha_H$  is the Hooe parameter. The exponent  $\gamma$  accounts for the departure from the ideal  $1/f$  slope.



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**Fig. 3** Normalised low-frequency noise of four HEMT types

$V_{DS} = 0.05\text{V}$

The normalised noise spectra of the four HEMT types are shown in Fig. 3. In these results, the 60Hz line power and its harmonics have been subtracted out and the spectra have been smoothed for clarity. Two types of spectra are apparent. Devices (i) and (iii) have almost ideal  $1/f$  slopes with  $\gamma$  equal to 1.11 and 0.96, respectively. For device types (ii) and (iv), there is a significant departure from the  $1/f$  slope with a very broad noise peak near  $2 \times 10^4\text{Hz}$ . Measurements showed that, over a range of temperatures, the peak moves in frequency, implying that a thermally activated process involving generation-recombination (g-r) at a trapping level is the probable cause. By comparing the details of the four structures, it appears that the g-r peak is associated with the combination of the InAs(Si) doping and the alloying of the contacts. However, since the overall noise level for this combination is lower than for the undoped or unalloyed cases, (i) and (iii), the g-r component may simply be revealed more prominently. It should also be noted that for all the devices in Fig. 3, the variation of  $S_V$  against  $V^2$  is linear from 0V to more than 0.2V.

**Table 1:** HEMT channel properties and Hooge parameters

HEMT type	$\mu$	$n_s$	$\alpha_H$
	cm <sup>2</sup> /Vs	cm <sup>-2</sup>	
(i)	29,000	$9.0 \times 10^{11}$	$8 \times 10^{-3}$
(ii)	20,000	$1.9 \times 10^{12}$	$1 \times 10^{-3}$
(iii)	20,000	$2.2 \times 10^{12}$	$1 \times 10^{-2}$
(iv)	18,000	$2.7 \times 10^{12}$	$2 \times 10^{-3}$

A summary of the channel properties and the Hooge parameters of the four HEMT types is given in Table 1. The Hooge parameters, calculated from eqn. 1 using values of  $N$  based on the measured current, ranged between  $10^{-3}$  and  $10^{-2}$ . It should be noted that there is no correlation between the channel mobility and the Hooge parameter. This implies that the noise level for these devices is dominated by traps and/or dislocations so that any fundamental relationship to the mobility is hidden.

These results are the first broadly reported measurements on the low-frequency noise of HEMTs in this material system. Therefore, some caution should be exercised in drawing general conclusions about this technology. It should be kept in mind that no effort has been made at this point to optimise the layer structure, the growth parameters, or the processing procedure in order to minimise the noise. Although  $\alpha_H$  in these devices is about one order of magnitude larger than in the latest InP- or GaAs-based HEMTs, the values obtained in this Letter appear reasonable for a relatively immature technology with a threading dislocation density greater than  $10^7 \text{ cm}^{-2}$  due to lattice mismatch in the metamorphic growth. It should also be noted that early AlSb/InAs HEMTs which were doped with an As-soak technique, and had several other dif-

ferences from the devices considered here, yielded  $\alpha_H$  values in the same range reported in this Letter. This suggests that the noise is not strongly dependent on the specific details of the layer structure, but rather on a more general aspect of the structure such as an AlSb/InAs interface trap or the high dislocation density. Additional work is indicated to establish the primary cause of the noise and to modify the HEMT design to reduce it.

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